

FINAL REPORT

AISRP Program

Development of an IUE Time Series Browser

by Derck Massa

Background:

The object of this program is to make the time series data obtained by The International Ultraviolet Explorer (*IUE*) satellite more accessible, through the development of a Web-based browser. *IUE* operated successfully for more than 17 years, accumulating more than 100,000 science exposures, which are widely acknowledged as an invaluable scientific resource that will not be duplicated in the foreseeable future. We have searched this archive for objects observed 10 or more times with the same wavelength coverage and spectral dispersion over the lifetime of *IUE*. Using this definition of a time series, we find that roughly half of the more 100,000 science exposures are members of such time series.

Identifying these data sets and developing a means to easily examine them for variability would be an extremely useful scientific asset. We have already identified the data sets and developed a prototype for a browser which operates over the Web. We are now producing a fully operational version of the browser. The browser will enable a researcher to inspect the repeated observations for variability and to examine each member spectrum individually. Further, once the researcher ascertains that a specific data set is worthy of further investigation, he will be able to download the entire data set through links on the browser page for further scrutiny on the researcher's home computer.

A working version of the low resolution browser has been completed and can be accessed at the URL

<http://derckmassa.net/browser/>

In addition, a paper describing the browser has been drafted and will be submitted to the *Publications of the Astronomical Society of the Pacific*. A copy of this paper is attached.

An IUE Time Series Browser

D. Massa¹

ABSTRACT

The International Ultraviolet Explorer (*IUE*) satellite operated successfully for more than 17 years. Its archive of more than 100,000 science exposures is widely acknowledged as an invaluable scientific resource that will not be duplicated in the foreseeable future. We have searched this archive for objects which were observed 10 or more times with the same spectral dispersion and wavelength coverage over the lifetime of *IUE*. Using this definition of a time series, we find that roughly half of the science exposures are members of such time series.

This paper describes a WEB-based *IUE* time series browser which enables the user to visually inspect the repeated observations for variability and to examine each member spectrum individually. Further, if the researcher determines that a specific data set is worthy of further investigation, it can be easily downloaded for further, detailed analysis.

Subject headings:

1. Introduction

The International Ultraviolet Satellite (*IUE*) was launched in 1978 and remained in service until it was turned off in 1996. *IUE* obtained spectra in two ultraviolet (UV) wavelength bands: a short wavelength band ($1150 \leq \lambda \leq 1980 \text{ \AA}$), and a long wavelength band ($1850 \leq \lambda \leq 3350 \text{ \AA}$). Spectra could be obtained in one of two dispersion modes: low dispersion (whose resolution varied from of 5-8 \AA , depending on wavelength) and high dispersion (whose resolution varied from 0.1-0.3 \AA) and through one of two aperture, a small circular aperture, $\sim 3''$ in diameter, and a large rectangular aperture, $\sim 9.5 \times 22''$, aperture. One observation, in either dispersion mode, covered the complete wavelength band. Therefore, a single *IUE* spectrum was obtained in one of eight basic configurations: either short or long wavelength in either low or high dispersion and through either the large or small aperture. Additional details about the detectors (there were 2 for each wavelength band), pointing, etc., can be found in Boggess et al. (1978) and at the Multi-mission Archive at Space Telescope, MAST (<http://archive.stsci.edu/mast.html>).

¹SGT, Inc., NASA/GSFC, Mailstop 665.0, Greenbelt, MD 20771; massa@derckmassa.net

During its more than 17 year lifetime, *IUE* obtained pointed observations of more than 100,000 spectra of roughly 9300 objects, making it one of the most prolific space based astronomical observatories to date. Many of these observations were acquired as part of programs aimed at investigating individual objects or phenomena or groups of objects. However, *IUE* was also often used to obtain *time series observations* of specific objects. These objects spanned the full range of astronomical bodies, from binaries (e.g., Penny et al. 1999), variable stars (e.g., Burger, 1982), hot star winds (e.g., Massa et al. 1995), symbiotic stars (e.g., Gonzalez-Riestra et al. 1999), X-ray binaries (e.g., Stricklan et al. 1997), novae (e.g., Shore et al. 1996), super novae (e.g., Pun et al. 1995), AGN, (e.g., Reichert, 1994), QSOs (e.g., von Montigny et al. 1997), BL Lacs (e.g., Pian et al., 1997), and numerous other objects. The *IUE* coverage of novae and super novae are especially notable since it was the only UV instrument to date which could respond to episodic events within a matter of minutes from the time the project was informed of its occurrence.

The longevity of *IUE* also resulted in repeated observations that are unique for their long temporal baseline. Furthermore, this same longevity also resulted in many “popular” objects being observed repeatedly over its lifetime. These observations also constitute time series, although they were not necessarily planned. Rather, different programs often reobserved the same object for different purposes.

Together, both the planned and serendipitous time series resulted in an archive that is veritable treasure trove of time series observations. In fact, if we define a time series as 10 or more observations of the same object obtained with the same dispersion and wavelength coverage over the lifetime of *IUE*, then more than 50% of the 100,000 *IUE* observations fall into this category. Therefore, *roughly half of the data obtained by IUE are in time series*. The breakdown of these time series by wavelength and dispersion is given in Table 1.

Table 1: Time Series Data Sets

Camera	Disp	Sets	No. of Spectra	Mean No. per set
SWP	low	462	16955	36.3
SWP	high	316	12515	39.6
LW	low	352	12640	35.9
LW	high	251	8106	32.3

Note that the number of sets is not necessarily the same as the number of objects which have time series data. This is because it often happens that the same object has a time series at both long and short wavelengths or, less frequently, both low and high dispersion. Nevertheless, there are time series for more than 700 different objects.

In spite of all of the references cited above, one must keep in mind that only a small fraction of the time series were ever published. Furthermore, the time series which were published, covered the data available at that time (which is often a small portion of the final total) and were often

presented in very different ways. The latter point is actually a very important, since it impedes the ability to compare time series for the same object obtained at different epochs and time series for similar objects. Phenomena common to several time series may escape detection unless data can be inspected in a common format. Only then, can the researcher place things into context, and determine which phenomena are common, and which are exceptional. Finally, data handling and display techniques have evolved greatly since 1978, and many of the early analyses were very crude by current standards.

2. The Need for a Temporal Browser

The *IUE* time series are clearly a remarkable scientific resource. At no time in the foreseeable future will there be a data set whose temporal coverage will rival that of *IUE*. Not only did it last for more than 17 years, the observations were all obtained with the same instrument in one of a very limited set of configurations which did not change. It is clear, that to fully utilize this valuable resource the data must be made accessible. Only then will researchers be able to easily assess whether a particular data set exists and whether it is worthy of further investigation. However, the enormity of the data involved can make them very difficult to access and inspect, especially for those not accustomed to time series analysis.

Even a preliminary inspection of a data set consisting of spectra obtained over a number of years, can require considerable effort. First, a list of relevant spectra must be determined and acquired. Next, the data must be culled for instrument specific problems. Finally, the data must be assembled into a form that is amenable to inspection. All of these steps take require some effort. On the other hand, for someone who is familiar with the data and experienced with the common approaches used to display and inspect time series data, it is a tractable problem.

Thus, in order to provide the community with means to instantaneous access *IUE* time ordered data, we have developed a temporal browser for the *IUE* low dispersion data. The next sections outline the contents of the browser and possible future enhancements.

3. The *IUE* Temporal Browser

The *IUE* temporal browser is a WEB based tool which is structured as follows:

1. The user is presented with a WEB page containing links to some informational material and to the low resolution short and long wavelength browser catalogs.
2. Under the links for each wavelength mode, there is a listing all objects with 10 good quality spectra obtained over the lifetime of *IUE* in that wavelength. The listing is grouped by the type of astrophysical object (based on the *IUE* Object Classes), with the individual listings for each group ordered by Right Ascension. There are 9 categories (Solar System objects are

excluded): O and WR Stars, B Stars, A Stars, Young Stars, Late-Type Stars, Compact Stars (Wd, sd, HB, PN, Pulsar, etc.), Eruptive Stars (Novae, SN, Symbiotic, etc.), Misc. Stars, and Extragalactic objects.

3. Each line in the listing is a link to an individual temporal browser page.

Figures 1–3 provide examples of individual browser pages. These figures demonstrate that each browser page consists of 6 basic elements.

1. **Color Bar:** Each dynamic spectrum has its own color bar across the top of the figure. This shows the range of normalized values used in the dynamic spectra. The range varies from one to the next, since some cover a rather large range and others vary by only a few percent. Automatically finding the proper range for a given object is a challenging task, and we have used an approach which keys off of percentiles and has provided good overall results. However, in a few cases the limits had to be inserted manually.

2. **Dynamic spectrum:** The main portion of the page is a GIF image of a dynamic spectrum. Dynamic spectra are a well known tool in the analysis of spectral time series (e.g., Geis & Kullavaniyaya 1988, Massa et al. 1995, Kaper et al. 1996). These are 2-dimensional images of time ordered, normalized spectra. The ordinate is time, and the abscissa is wavelength. Each horizontal strip in the image is a single spectrum which has been normalized by the sample mean. These spectra are derived from the MAST NEWSIPS (Nichols & Linsky 1996) MXLO files. These were corrected using the Massa & Fitzpatrick (2000, F&M hereafter) algorithms, which correct residual time dependent systematics in the NEWSIPS MXLO files. These systematics can be significant over long (several year) time intervals (see M&F for details). The dynamic spectra in the browser pages differ from those normally used in one respect. Because the time sampling is often very irregular, it was decided not to use the traditional linear time axis. Instead, the spectra are simply stacked sequentially. This avoids problems displaying series with a few short periods of intense monitoring of the object separated by large time gaps. In such a case, a linear time scale would cause all of the data in the dynamic spectrum to be squashed into a few small strips and the rest of the image to be blank.

Although visual inspection of dynamic spectra for variability is clearly a qualitative process, it turns out to be extremely sensitive. This is because the eye is simultaneously checking for correlations in both time and wavelength, to determine whether a feature which is present at one time is part of a trend and whether a feature present at one wavelength extends to adjoining ones. The example browser pages (Figs. 1–3) contain several examples of such correlations. Although these are easy to detect qualitatively by simple visual inspection, they can often escape detection by simple, standard quantitative tests. For example, if there are many spectra of an object and it experienced a single eposidic spectral change, such a change may easily not be detected in a simple wavelength by wavelength analysis of variance. On the other hand, the eye would immediately notice that several few σ events occurred together in both time and wavelength. Furthermore, an experienced researcher will also verify any perceived variability on the fly. This is usually done by

comparing a suspected variability in one line, for example C IV $\lambda 1550$, to other lines such as Si IV $\lambda 1400$ and N V $\lambda 1240$, whose ionization potentials bracket C IV and would be expected to react in step.

Note: each spectrum in the dynamic spectrum is an active link to the MAST IUE spectral browser for that spectrum.

3. Temporal plot: Because the ordinate of the dynamic spectrum is sequential instead of linear, we needed to devise another means to display the temporal sampling. Therefore, we plot the times at which the individual spectra were obtained to the right of the dynamic spectra. This plot is aligned with the dynamic spectrum. It has time from the first observation as the abscissa and the ordinate is also the sequence number. In this way, one can immediately see the progression of the time sampling and which spectra in the main image were taken at which time. When the time sampling curve is nearly vertical for several spectra, this means that they were obtained over a very short time interval.

4. Data Quality Bar: Directly attached to the right side of the dynamic spectrum and to the left of the time scale, is a strip which gives the exposure level of each spectrum relative to the best exposure in the set. This turns out to be a useful means for quickly determining whether a particular spectrum, which does not appear to fit into the sequence, may be a poor exposure and, therefore, not to be trusted.

5. Mean Spectrum: Attached to the bottom of the dynamic spectrum is the mean spectrum of the set which was used in the normalization process. While this has little meaning in a highly variable object, it typically contains all of the prominent spectral features and enables one to identify which aspects of the spectrum are changing.

6. Links: Below the dynamic spectrum and its supporting plots, is a set of links. These are:

- *Information on the contents of the dynamic spectra:*

This is a link to pages with information about the contents of the dynamic spectra.

- *List of spectra used to construct the dynamic spectrum:*

This is a link to a detailed list of the spectra used to construct the dynamic spectrum, along with details about the time they were obtained, the length of the exposure and the continuum and background levels for the exposure (extremely important in evaluating the quality of the exposure). Each EID (which stands for Entry ID) listing in the table is a link to the corresponding MAST spectral browser page.

- *List of spectra rejected for use in the dynamic spectrum:*

This link goes to a simple list of the spectra which were automatically rejected from the dynamic spectrum. These links are useful for determining whether the automated rejection scheme functioned properly. Currently rejection from the sample is done only for spectra which have less than 20% of the data points usable. This is determined by having the software inspect quality flags within the files for each spectrum. Spectra with less than 80% of the data usable or with a mean signal-to-noise ratio less than 2 are included in the plots,

but excluded from the calculation of the mean spectrum.

- *Link to a MAST retrieval web page to download the spectra:*

When this link is followed, it automatically opens a MAST download page for all of the spectra used to construct the dynamic spectrum. If some one determines that a time series is worth pursuing, then this link will enable them to obtain all of the relevant data directly. Note, however, that the MAST spectra have not been corrected for the residual systematics described by M&F, and these can be larger than 15% at some wavelengths for spectra separated by long time intervals. However, the M&F correction software is available from MAST.

- *This reduced data product was developed under the NASA AISRP*

This provides a link to NASA's AISRP program, which supported the construction of the browser.

The current version of the browser is only for low resolution data and can be accessed at:

<http://derckmassa.net/browser/>

4. Future Development

This initial version of the browser is still evolving, and some possible future enhancements are being considered. One would be reprocess all of the spectra through the M&F software and make the corrected spectra available for down loading. Another would be to make FITS images of the dynamic spectra, so that users can download them and rescale them at will, in order to enhance specific features that might interest them.

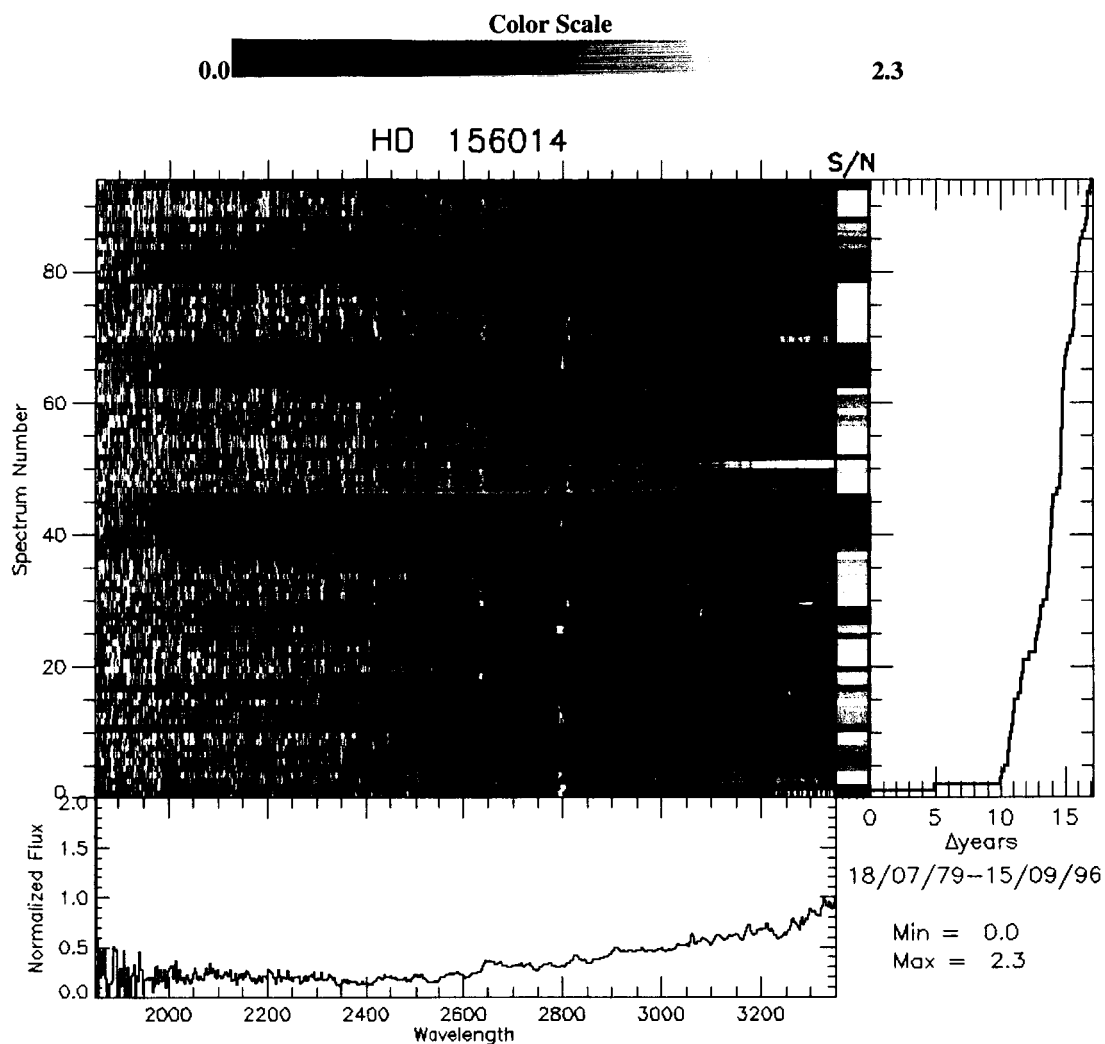
Finally, the browser currently exists *only* for low dispersion data, in spite of the fact that there are nearly as many time series for high dispersion data (see, Table 1). However, dealing with the high dispersion data is problematic. There are known *time-dependent systematics* in the *IUE* NEWSIPS high dispersion spectral extractions (Massa et al. 1998, Smith 1999). However, many of the high dispersion time series were obtained over short time intervals, typically less than a week or two. These data sets should be relatively free of the time-dependent systematics and may be the subject of an expansion of the current browser.

This project was supported by NASA's AISRP program. I would also like to thank Michael Van Steenberg, Nancy Oliverson and Patricia Lawton for help with the *IUE* data and the MAST personnel, especially, Karen Levey.

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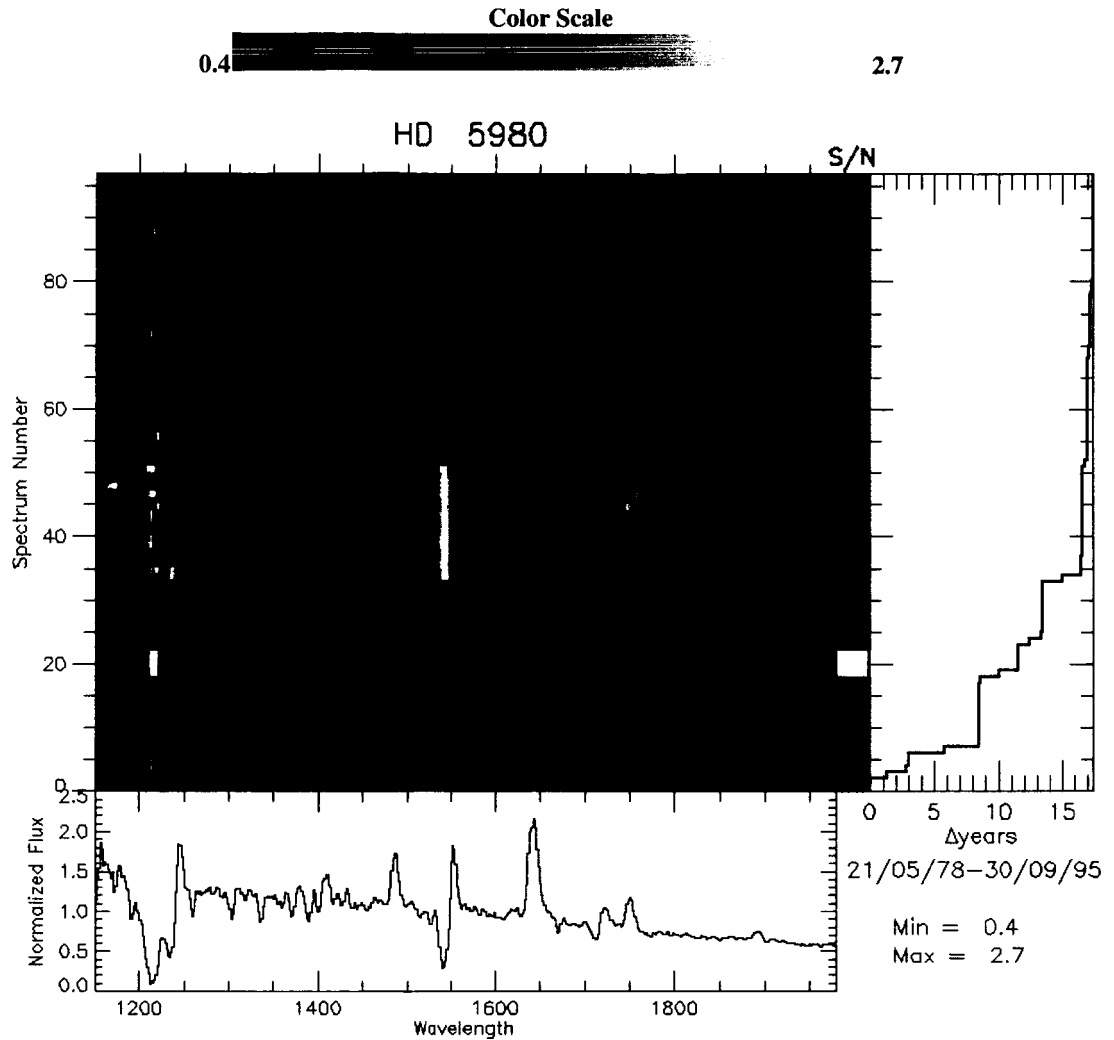
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- Information on the [contents of the dynamic spectra](#).
- [List of spectra](#) used to construct the dynamic spectrum.
- [List of spectra](#) rejected for use in the dynamic spectrum.
- Order the spectra from [MAST](#).
- This reduced data product was developed under the NASA [AISRP](#).

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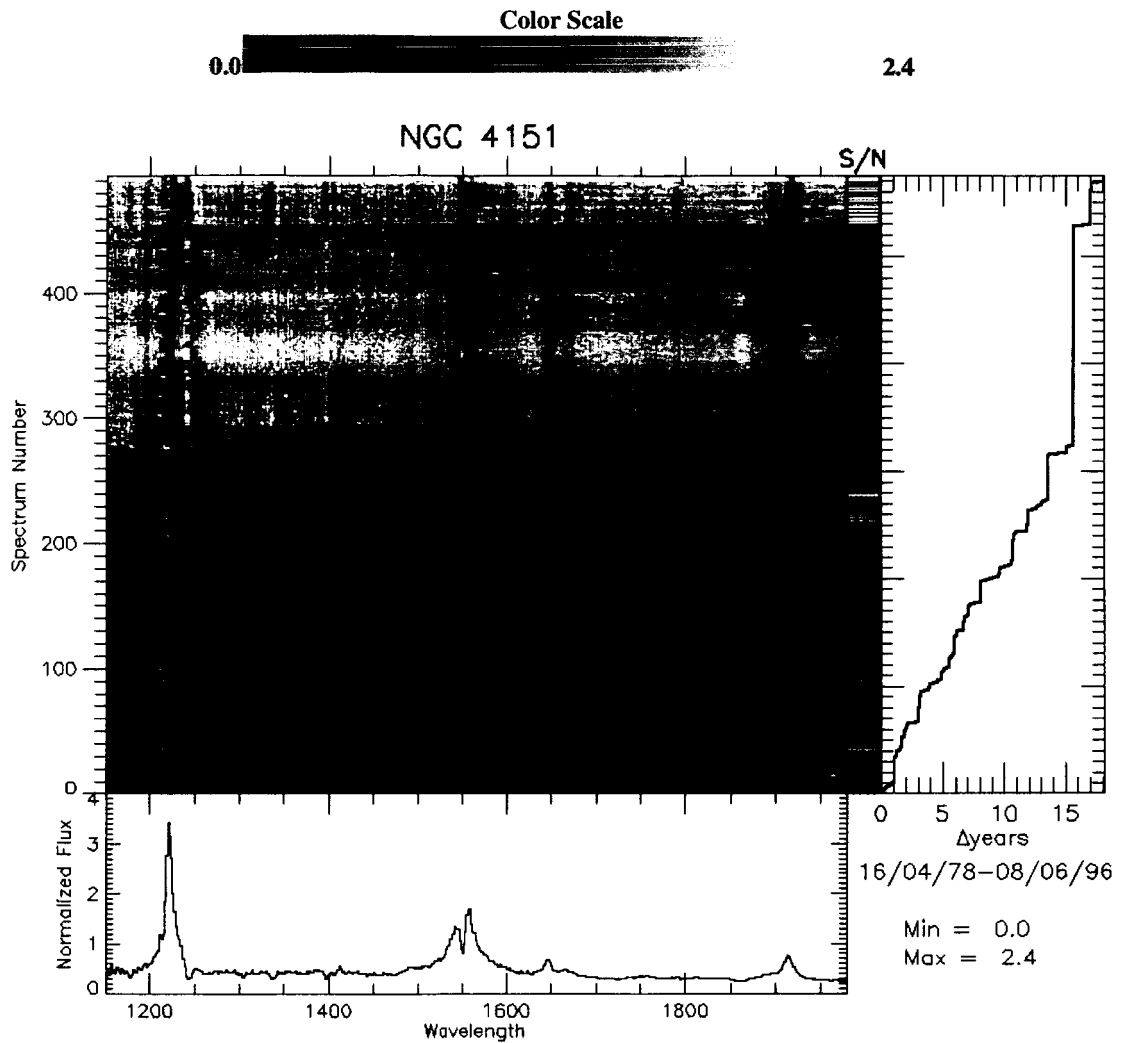
Fig. 1.— Browser page for HD 156014. This is a late-type irregular variable. It was monitored regularly over the last 7 years of *IUE*. Several cycles of brightening and dimming are apparent, as are line shifts due to gas motions in the outer envelope (esp. at Mg II $\lambda\lambda$ 2800).



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Fig. 2.— Browser page for HD 5980, an early type star which underwent large spectral changes over the lifetime of *IUE*. This dynamic spectrum shows that its lines varied in strength, the entire UV brightened, and the continuum became redder (the long wavelengths brightened more than the short ones).



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Fig. 3.— NGC 4151 was one of the most intensely monitored objects, and its UV continuum varied strongly throughout. This page shows how the line and continuum intensities varied differently, and how the velocities of some of the lines changed. Note the 200 spectrum time series in year 15.